10/030366

PCT / CA 00/00808

#2

Office de la propriété intellectuelle du Canada

Un organisme d'Industrie Canada

Canadian Intellectual Property Office

An Agency of Industry Canada

02 AUGUST 2000 (02.08.00)

REC'D 25 AUG 2000

WIPO PCT

CA00/00808

Bureau canadien des brevets

Certification

Canadian Patent Office

Certification

4

La présente atteste que les documents ci-joints, dont la liste figure ci-dessous, sont des copies authentiques des documents déposés au Bureau des brevets.

This is to certify that the documents attached hereto and identified below are true copies of the documents on file in the Patent Office.

Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,276,962**, on July 7, 1999, by **UNIVERSITÉ DE MONTRÉAL,** assignee of Christer Sinderby, Jennifer Beck and Lars Lidstrom, for "Electromyogram Signal Analysis Method and System for Use With Electrode Array"

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Best Available Copy

S. Grégoire

Agent certificateur/Certifying Officer

August 2, 2000

Date

Canada

(CIPO 68)

OPIC CIPO

Electromyogram signal analysis method and system for use with electrode array

Background of invention

1. Field of the invention

The present invention relates to electromyography (EMG) analysis methods and system in which EMG signals, that contain physiological information pertaining to the diaphragm, of reverse polarity obtained on opposite sides of the center of the striated muscle electrically active region center are a) corrected for electrode filtering by implementing a weighting function and b) integrated/summed. The area/power of the new signal will provide improvement of the signal to noise ratio and minimize influence of electrode filtering due to changes in the position of the electrode array relative the muscle's electrically active region center. It also accounts for differences in anatomy between individuals and differences in inter-electrode distance and design.

2. Brief description of the prior art

The physiological mechanisms which generate myoelectrical activity when the muscle contracts have been known and understood for long time. In particular, how to record signals from the muscle is one of the most extensively theoretically described topics in physiology. Although the theoretical understanding is impressive, the bio-physiological application of these theories is, in practice, still partly deficient. As of today, we are only aware of one system for standardized and automatic processing which take into consideration factors as electrode filtering due to changes in the position of the electrode array relative the muscle's electrically active region center. This technique is limited with respect to its adaptability to changes in inter-electrode distance and does not optimize the use of signals available along the electrode array with varying anatomy and interelectrode distance. The previous technology does not include the use of weighting functions to correct for inclusion of signals obtained from electrode pairs that are not symmetrically positioned with respect to the center of the muscle's electrically active region.

Objects of the invention

The object of the present invention is therefore to overcome the above described drawbacks in the prior art.

Summary of the invention

More particularly, in accordance with the present invention, there is provided a method and system for producing an electromyographic signal having improved signal to noise ratio related to a striated muscle, defining a muscle electrically active region with a center and provide correction for filtering of the electromyographic signal due to the relative position of the electrode array with respect to the muscle's electrically active region center.

Electromyographic signals produced by the muscle are first detected by means of an array of electrodes passing through the center of the muscle electrically active region. Each electrode detected electromyographic signal comprises an electromyographic

component and a noise component, and the position of the center of the muscle electrically active region can be detected through a reversal of polarity of the electromyographic components of the electrode detected electromyographic signals.

The area/power of each electromyographic signal obtained on either side of the electrically active region center, is multiplied/divided by a weighting function. The weighting function is derived from a mathematical model for a perpendicular bipolar transfer function and adjusts the area/power of each electromyographic signal with respect to the relative position of the electrode array with respect to the muscle's electrically active region center. The final signal is then obtained by calculating the sum/mean values of all the corrected areas/power of each electromyographic signal obtained on the electrode array. The processing can be performed in the time domain or in the frequency domain.

The weighting function contains correction for electrode filtering due to a) the relative location of the electromyographic signals electrically active region center to the electrode pairs used to obtain a differential signal, b) distance filtering between signal source and electrodes, c) size of the electrically active region and , d) inter-electrode distance. Knowing the position of the electrically active region the model can produce weighting functions correcting for both cancellation effects and distance damping effects.

An evaluation of all electromyographic signals can be performed on the signals for their relative components of electromyographic signals and noise signals. Thus, if preferred the summation of signal area/power along the elctrode array can be limited to signals that contain physiological information pertaining to the diaphragm. This evaluation of signals content can be performed by applying signal quality indexes for detection of signal noise ratio maximum to minimum drop in power density, power spectrum deformation, and electrocardiogram/esophageal peristalsis detectors These have been previously described in Patent 5.671,752). Evaluation of signals for their relative components of electromyographic signals and noise signals can also be obtained by subtracting signals obtained on opposite sides with symmetrical position to the electrically active region center and comparing the any area/power of the subtracted/added signals (This have previously been described in Trigger patent application). If a first electromyographic signal detected by the electrodes of the array on the first side of the center of the electrically active region is subtracted from a second electromyographic signal detected by the electrodes of the array on the second side, opposite to said first side, of the center of the electrically active region. The first electromyographic signal has an electromyographic component of a first polarity, and since the second electromyographic signal has an electromyographic component of a second polarity opposite to the first polarity. The subtraction subtracts the noise components of the first and second electromyographic signals from each other but adds the respective electromyographic components of the first and second electromyographic signals together produce a signal with high electromyographic component and low noise component. The addition adds the noise components of the first and second electromyographic signals to each other but subtracts the respective electromyographic components of the first and second electromyographic signals from each other and produces a signal with low

electromyographic component and high noise component. Comparison of the area/power/amplitude of the added and subtracted signals provides information about the relative contribution of noise and electromyographic components in the signal. Signals considered as not containing physiological information pertaining to the diaphragm can be replaced by predicted values or simply the last value considered to contain physiological information pertaining to the diaphragm. This replacement strategy can be applied on either each single signal obtained from the electrode array or on the summation signal representative for all or some of the signals obtained along the electrode array.

Brief description of the drawings

In the appended drawings:

Figure 1 is a schematic representation of a setup of the EMG analysis system in accordance with the present invention; (same as Fig 1 in patent 5,671,752)

Figure 2 is a section of esophageal catheter on which an array of electrodes of the EMG analysis system of Figure 1 is mounted; (same as Fig 2 in patent 5,671,752)

Figure 3 is showing a set of EMG signals of the diaphragm detected by pairs of successive electrodes of the array of Figure 2; (same as Fig 3 in patent 5,671,752)

Figure 4 to this flow chart showing a method for determining the position of the center of the electrically active region of the diaphragm along the array of electrodes of Figure 2; (same as Fig 4 in patent 5,671,752)

Figure 5 is a graph showing the distribution of correlation coefficients calculated for determining the position of the center of the electrically active region of the diaphragm along the array of electrodes of Figure 2; (same as Fig 5 in patent 5,671,752)

Figure 6 is a graph showing measured electrode filtering effects along the electrode array for arrays of various interelectrode distances; (enclosed figure 6)

Figure 7 is a graph showing measured and predicted electrode filtering effects along the electrode array; (enclosed figure 7)

Figure 8 is a flow chart showing the steps of signal processing; (enclosed figure 8)

"disclosure"

Wanted signals (S) and signals (D) from disturbing structires are recorded with an electrode array having N electrode plates labeled n=1 to N. The array does not have to be linearly arranged; any configuration may be used.

The signal recorded at a certain electrode plate (n) depends on 1) the properties of the wanted signal source and the disturbing signal source (point sources or line sources with particular direction or curved line sources) and on 2) the distances ($r_s(n)$ and $r_d(n)$, respectively) from the sources to the electrode plate (n). Line source signals display a mixed frequency and distance dependent damping essencially described by modifiel bessel functions while point source signals are damped inversely proportional to the distance and independent of frequency.

Each electrode plate is passed through a weighting function (W(n), a frequency dependent filter) which may be positive negative or even zero prior to a summation of all contributions (n=1 to N) to give the output signal.

Describing the signal conditioning in the spectral domain (frequency dependence) we have the following expressions:

the signal u(n) at electrode plate (n) is

$$u(n) = S\, f_s[r_s(n)] + D\, f_d[r_d(n)]$$

the output signal (Out) is:

$$\text{Out} = \sum_{n=1}^{N} u(n)\, W(n)$$

Combining the two equations and rearranging the terms give

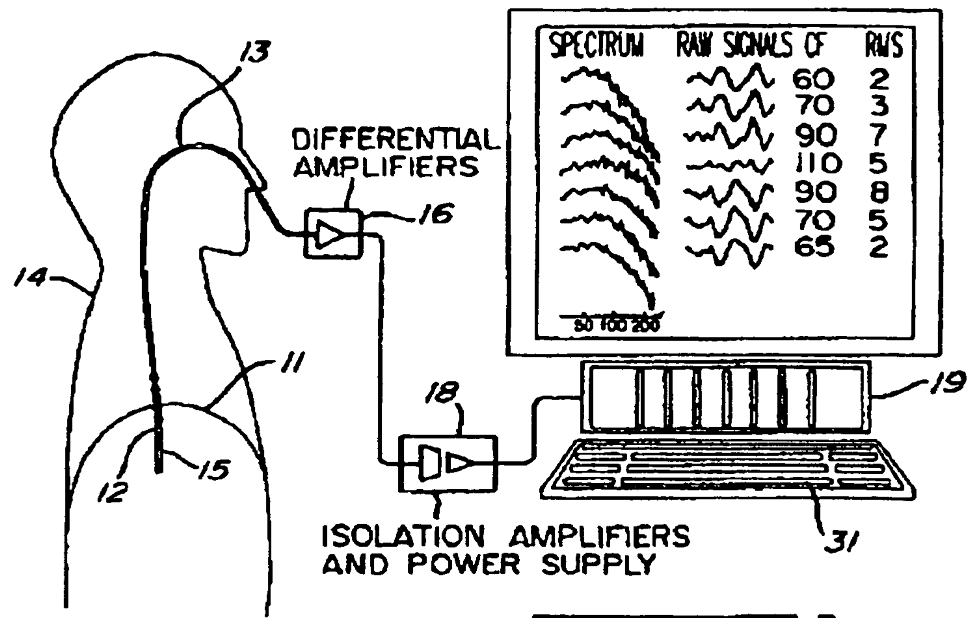
$$\text{Out} = S \sum_{n=1}^{N} f_s[r_s(n)]\, W(n) + D \sum_{n=1}^{N} f_d[r_d(n)]\, W(n)$$

In general terms, for a good performance, we have to maximize the first term and minimize the second one, or depending on the application at hand, utilize known filtering strategies to optimize the spectral distributions of wanted and disturbing signals. The optimization is performed by varying sign, strength, and spectral (complex) contents of the weighting filters W(n). This process can be guided by a priori knowledge of the type of signal source (line, point, etc) and the corresponding type of damping (modified bessel functions, invers distance damping, etc) and/or experimental knowledge of the signals spectral content.

One extreme situation occurs when no frequency dependence is assumed and the weighting factors are plus or minus unity. This is the situation in the so-called double subtraction technique used for picking up signals from the diaphragm muscle with the electrode array perpendicular to the muscle fiber direction. This simple double subtraction also has the property of reducing signals coming from outside the group of electrodes.

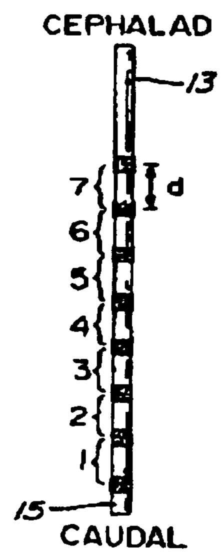
The use of **electrode arrays of arbitrary configuration** i combination with the use of **weighting functions which are also frequency dependent** to optimize the signal-to-disturbance ratio of the output signal.

The use of **summation of weighted contributions** from an electrode array of arbitrary configuration in such a way (weighting functions with different signs, strengths, and spectral responses) that the wanted signal is enhanced and the unwanted signals are suppressed.



13
DIFFERENTIAL
AMPLIFIERS
16
14
11
18
12
15
19
31
ISOLATION AMPLIFIERS
AND POWER SUPPLY
SPECTRUM
RAW SIGNALS
CF
RMS
60 2
70 3
90 7
110 5
90 8
70 5
65 2
50 100 200

FIG. 1



CEPHALAD
13
7
d
6
5
4
3
2
1
15
CAUDAL

FIG. 2

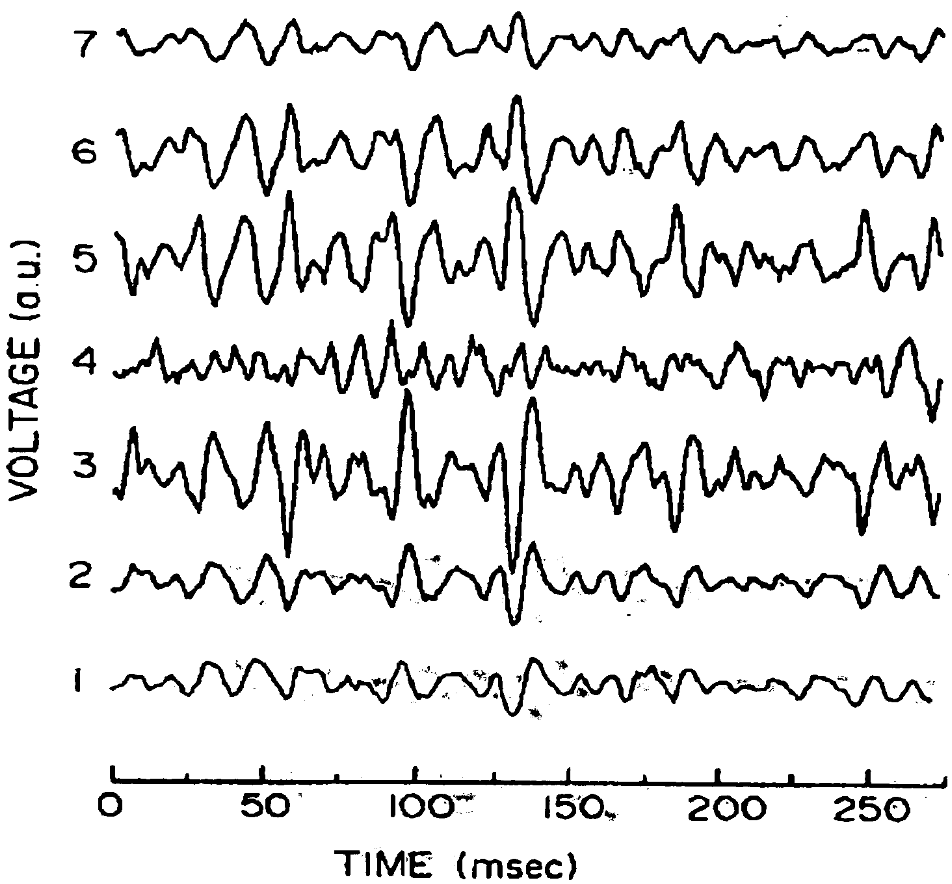


FIG. 3

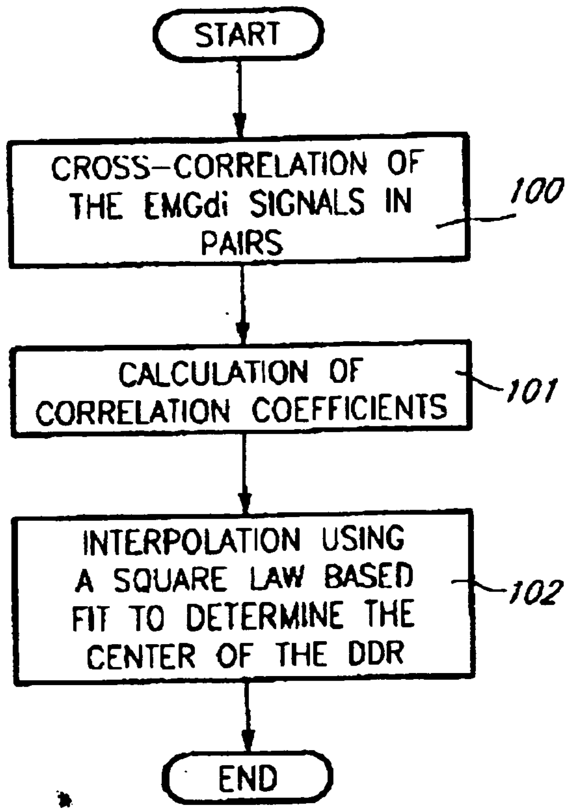
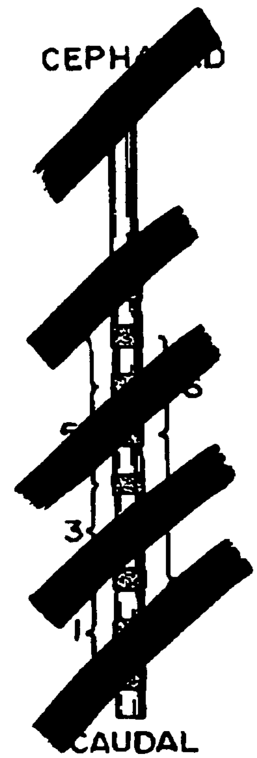

START
CROSS-CORRELATION OF THE EMGdi SIGNALS IN PAIRS
100
CALCULATION OF CORRELATION COEFFICIENTS
101
INTERPOLATION USING A SQUARE LAW BASED FIT TO DETERMINE THE CENTER OF THE DDR
102
END

FIG. 4



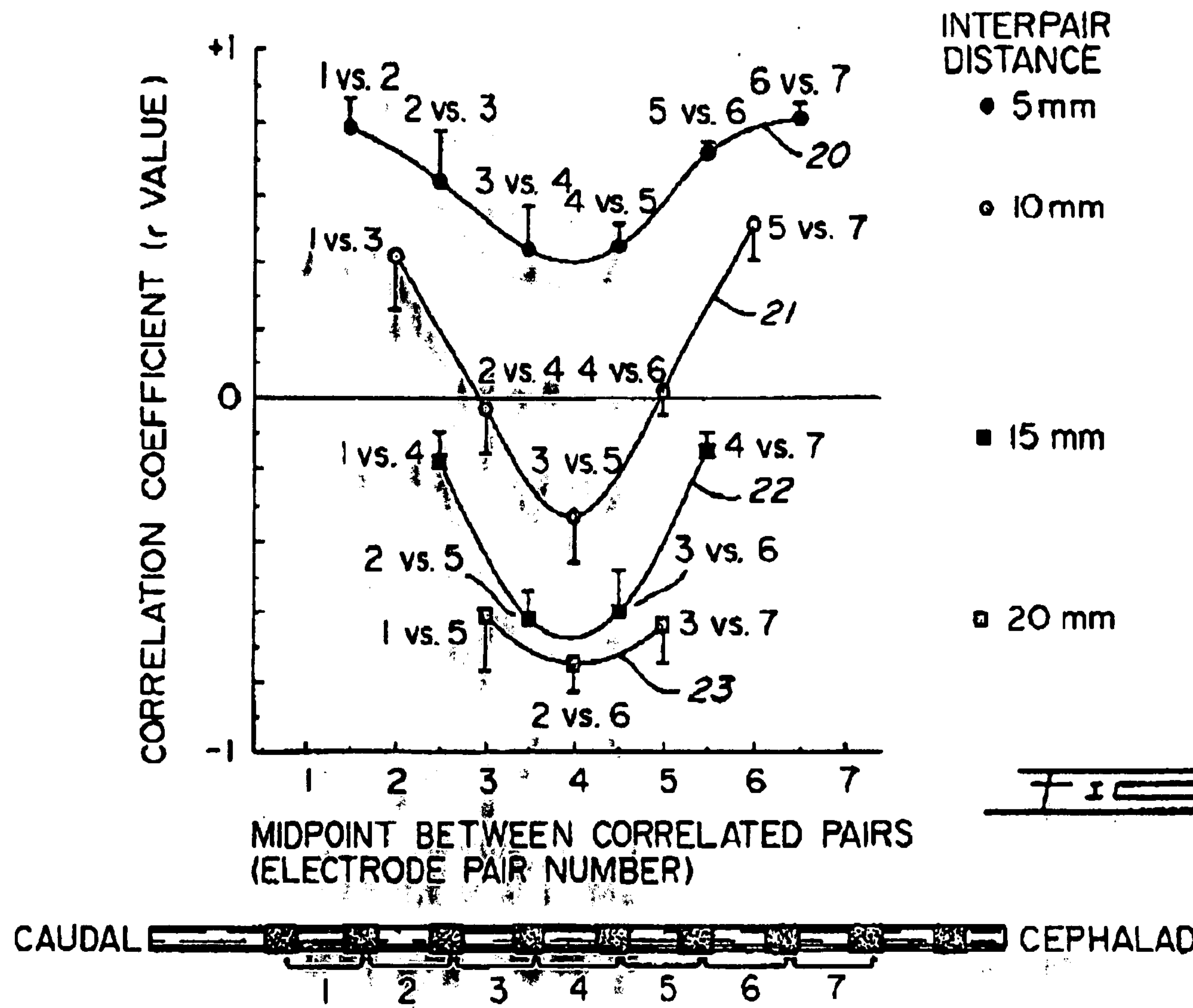

INTERPAIR
DISTANCE
● 5mm
○ 10mm
■ 15 mm
□ 20 mm
CORRELATION COEFFICIENT (r VALUE)
+1
0
-1
1 vs. 2
2 vs. 3
3 vs. 4
4 vs. 5
5 vs. 6
6 vs. 7
20
1 vs. 3
2 vs. 4
4 vs. 6
3 vs. 5
5 vs. 7
21
1 vs. 4
2 vs. 5
3 vs. 6
4 vs. 7
22
1 vs. 5
2 vs. 6
3 vs. 7
23
1
2
3
4
5
6
7
MIDPOINT BETWEEN CORRELATED PAIRS
(ELECTRODE PAIR NUMBER)
CAUDAL
CEPHALAD
1
2
3
4
5
6
7

FIG. 5

Fig 6

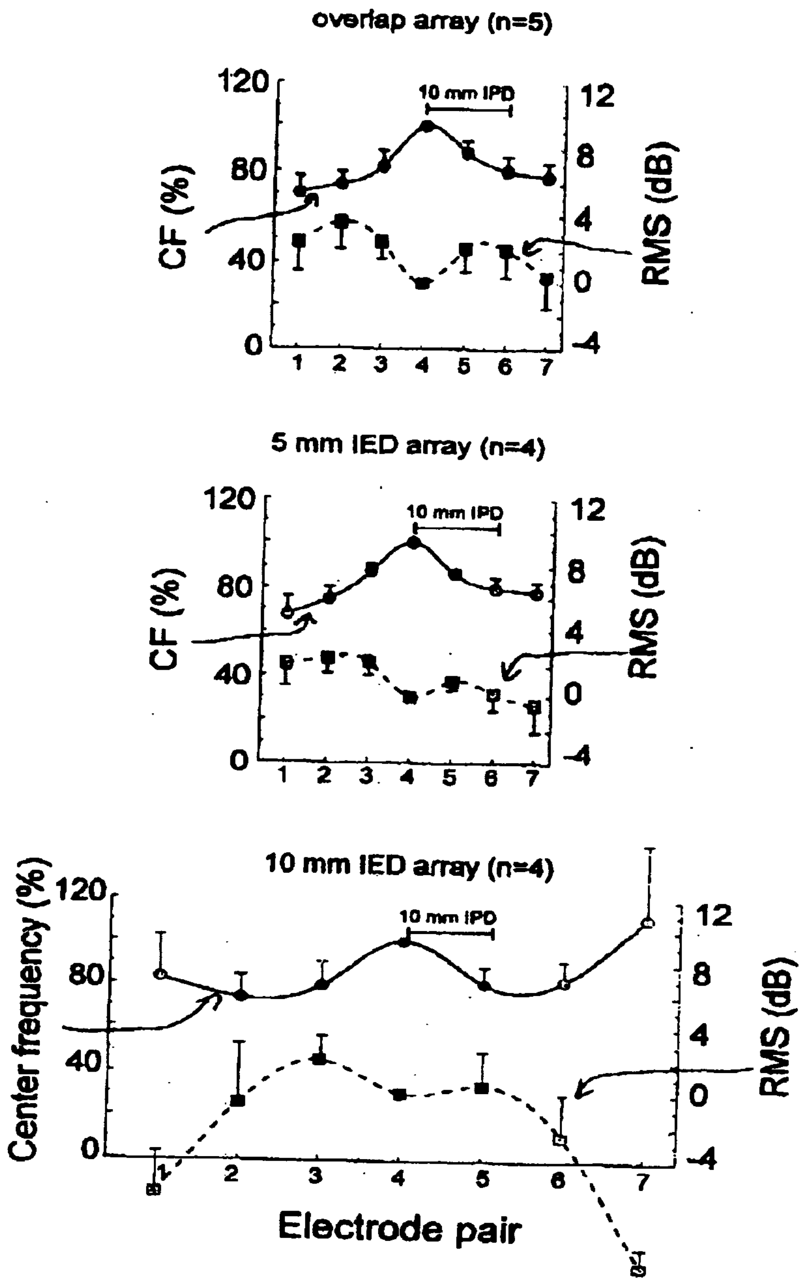

overlap array (n=5)
10 mm IPD
CF (%)
RMS (dB)
120
80
40
0
12
8
4
0
-4
1 2 3 4 5 6 7
5 mm IED array (n=4)
10 mm IPD
CF (%)
RMS (dB)
10 mm IED array (n=4)
10 mm IPD
Center frequency (%)
RMS (dB)
Electrode pair

Fig 7

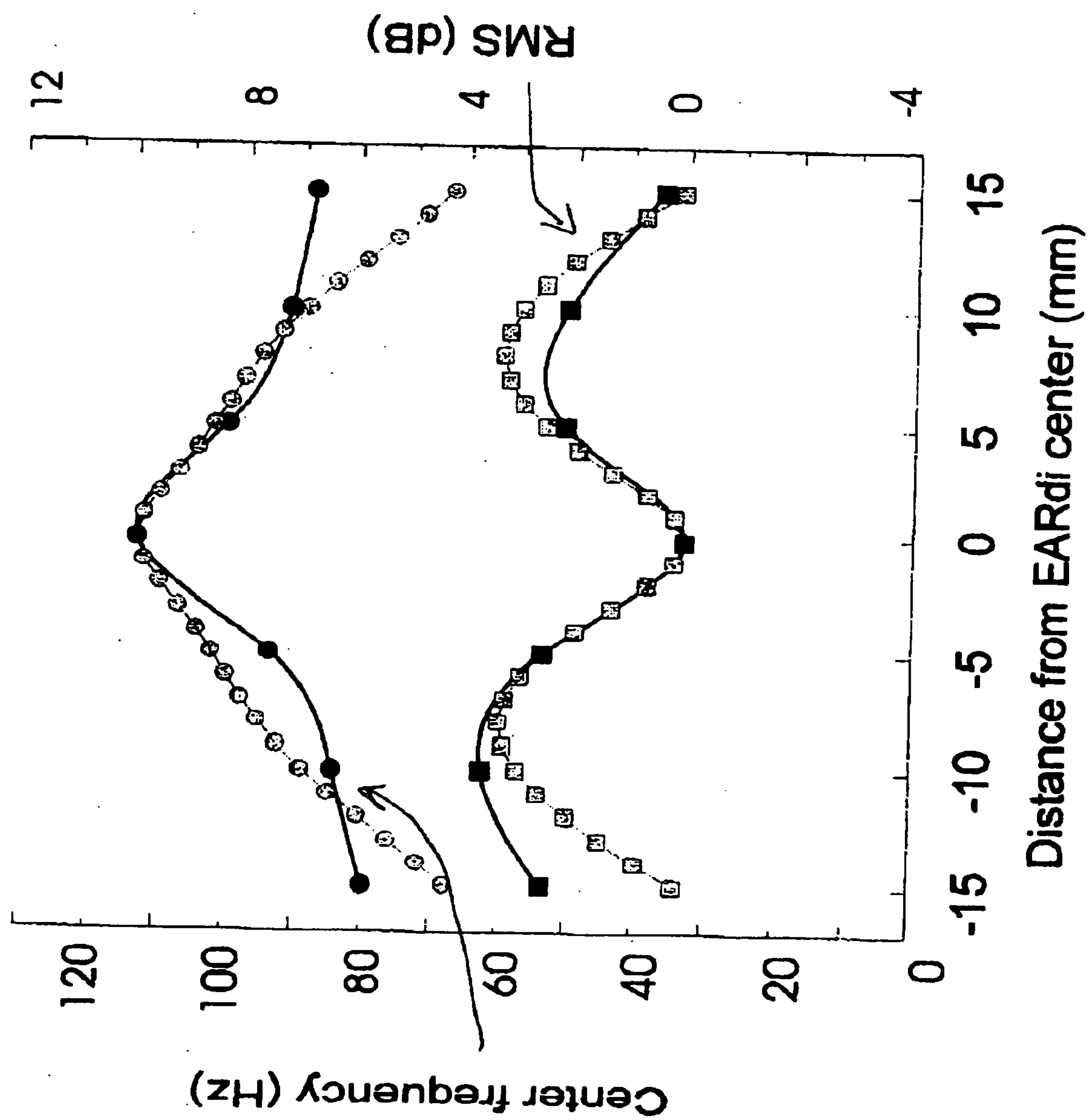
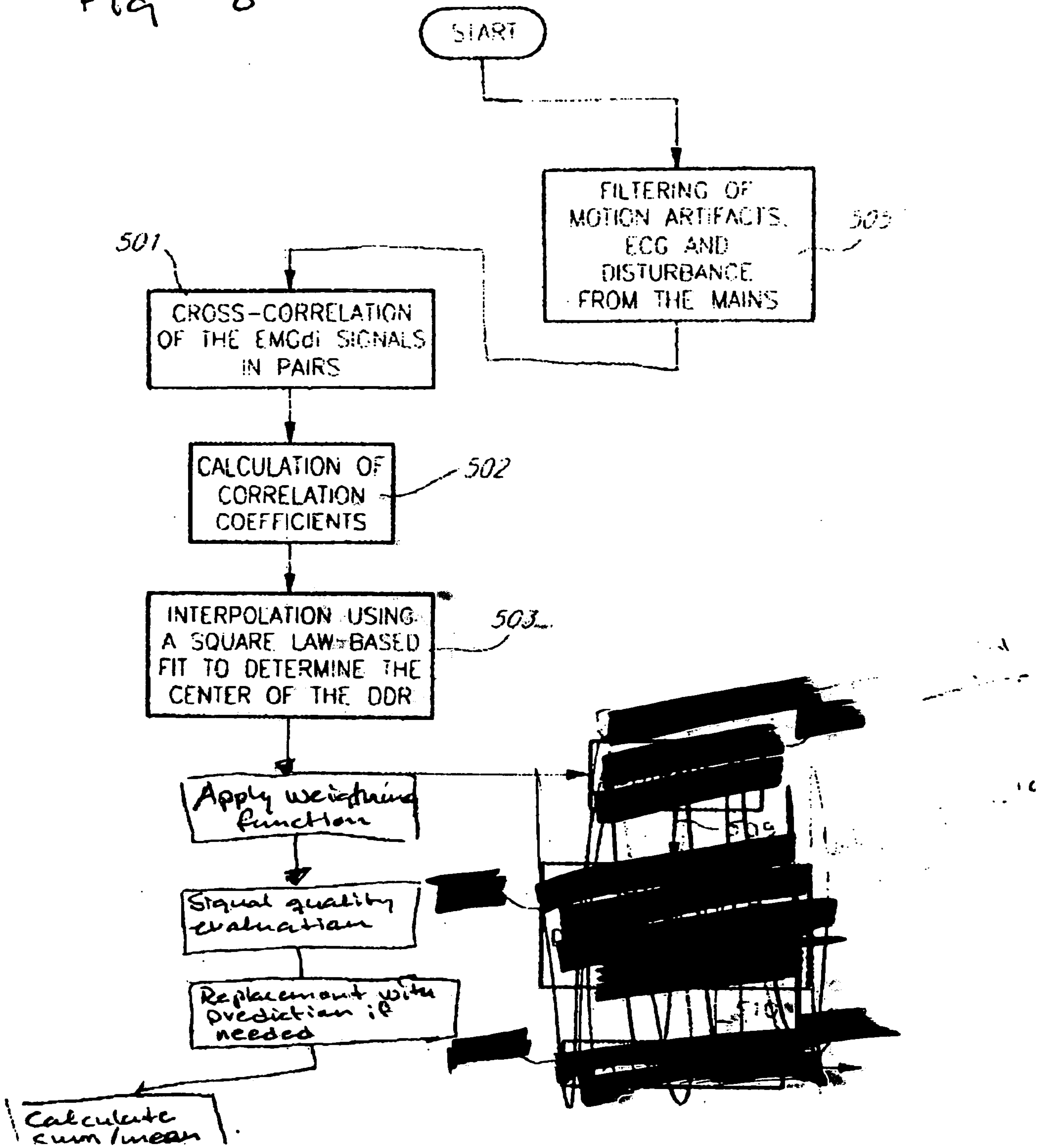

RMS (dB)
12
8
4
0
-4
Center frequency (Hz)
120
100
80
60
40
20
0
Distance from EARdi center (mm)
-15
-10
-5
0
5
10
15

Fig 8


START
FILTERING OF MOTION ARTIFACTS, ECG AND DISTURBANCE FROM THE MAINS
505
501
CROSS-CORRELATION OF THE EMGdi SIGNALS IN PAIRS
CALCULATION OF CORRELATION COEFFICIENTS
502
INTERPOLATION USING A SQUARE LAW-BASED FIT TO DETERMINE THE CENTER OF THE DDR
503
Apply weighting function
Signal quality evaluation
Replacement with prediction if needed
Calculate sum/mean
[redacted]